International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 4, Aug 2018, 357-370

REVIEW OF VARIOUS FEEDSTOCKS USED AND THE OPERATING CONDITIONS FOR BIODIESEL PRODUCTION

C. R. GIRISH

Department of Chemical Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, Karnataka, India

ABSTRACT

The energy crisis has become an important global issue because of the depletion of non-renewable fossil fuels. Therefore there is a need to explore alternative sources to solve the energy security problem. Different sources are available for energy production among which biodiesel is considered to be effective for reducing the dependency on fossil fuels. Biodiesel production causes less adverse impacts on the environment compared to petroldiesel and even the fuel properties are superior. Transesterification reaction was employed for producing biodiesel from various feed -stocks such as edible oil, non-edible oils, animal fats and used cooking oil etc. Thus, the present study investigates the various precursor materials used for biodiesel production. It also reviews the types of catalysts used and the effect of operating conditions on the transesterification reaction.

KEYWORDS: Biodiesel, Transesterification, Catalyst, Feed Stock & Non-Edible Oil

Received: May 18, 2018; **Accepted**: Jun 08, 2018; **Published**: Jul 07, 2018; **Paper Id**.: IJMPERDAUG201838

Original Article

INTRODUCTION

Due to the increase in population and improvement in the technology, there exists an enormous requirement of energy to the society in the recent time [1]. But because of the extensive use of fossil fuels for the energy production, these non-renewable sources will be exhausted in the near future [2]. At the same time, the prices of these fossil fuels like oil and gas are increasing at a rapid rate [3]. The use of these resources causes harmful effects on the environment such as global warming, the release of greenhouse gases and air pollutants [4, 5]. Also, the environmental agencies have laid strict regulations for reducing the pollution from the production of these fuels. [3]Thus it is required to search for an alternative source of energy to fulfill the needs of the mankind [2, 3]. The energy can be produced from different sources like geothermal, wind, solar and hydroelectric source [3]. The biofuel is considered to be most promising as an alternative to fossil fuel [6].

Biodiesel can be produced from various sources such as edible vegetable oils, non-edible oils, animal fats and other sources like used oil, grease etc [7]. In some of the developing countries which face a shortage of food supply, instead of edible oil low-cost feed stocks are preferred [8]. The advantage of vegetable oil is that it can be blended with petrol -diesel and used as fuel in ignition engines. The exhaust emission from the ignition engine contains the lower proportion of carbon dioxide, carbon monoxide and other toxic pollutants [3]. It was also investigated that vegetable oil has high viscosity and using them as fuel results in engine problems. Therefore the viscosity can be reduced by subjecting it to transesterification reaction to produce biodiesel [7]. The biodiesel has various benefits over petro diesel and it has the following significant features. It is renewable in nature, reduces the

emission of greenhouse gases, minimizes air pollution, non-toxic in nature, environmentally friendly, biodegradable [6, 9, 10, 11]. The fuel has chemical characteristics like high flash point, high cetane number, the absence of sulfur and aromatic compounds and it can be mixed with petro diesel in any proportions [9]. The production of biodiesel helps the society in creating the sufficient number of jobs in the regions where lesser economic activities happen [12]. It also encourages the entrepreneurs in various countries to invest in the technologies related to biodiesel production [13]. Thus the current paper examines the production of biodiesel from different feed stocks. It also reviews and summarizes the catalysts used, operating conditions, the yield obtained in the transesterification reaction.

TRANSESTERIFICATION REACTION

Various methods such as thermal cracking, dilution, catalytic cracking, and transesterification are used for the production of biodiesel from different feedstock [7]. Transesterification can be considered as an economically feasible method and yield obtained is higher.

In the transesterification reaction, the triglyceride molecules in the oil combined with an alcohol in the presence of a catalyst to form biodiesel (fatty acid esters) and glycerol. Basically, the viscosity of the oil is reduced and one ester of one type is converted to another type of ester [9, 14]. The reaction can be represented in the following manner

$$RCOOR' + R''OH \overset{catalyst}{\longleftrightarrow} RCOOR'' + R'OH \quad (1)$$

Oil Alcohol Ester Glycerol

The biodiesel is obtained as the lighter layer at the top and the glycerol formed as the bottom layer is generally used for preparing soap and other related cosmetic products [12].

VARIOUS FEEDSTOCKS USED

The biodiesel can be classified into three types such as first generation, second generation, and third generation biodiesel. It is mainly based on the feedstock. i.e.a source of feedstock, its use, availability, properties, amount of free fatty acids present and purity of the product obtained.

The first generation biodiesel is obtained edible oils whose fatty acids content is generally less than 1.5% [15]. The edible oil sources are soybean, palm oil, canola, peanut oil, coconut, sunflower, rapeseed oil, groundnut, corn, barley etc. [16, 17]. The production of biodiesel depends on the cost of feed oil. The first generation biodiesel is mainly produced from edible oils. 95% of the total biodiesel produced is from edible oils [18, 19]. It has the benefits that the feed oil is available abundantly and it can be easily and efficiently converted to biodiesel. By depending largely on these edible sources, it leads to the problems such as competition for fertile land which is used for agriculture, the necessity of water and fertilizer, the food chain is threatened, shortage of food supply, land use change, GHG footprint, deforestation, and economic stability [18,19].

The second generation biodiesel are obtained from the sources such as non-edible crops, used cooking oils or waste animal fats such as pork lard, beef tallow, poultry fat and fish oil [20]. They have free fatty acids content of less than 4%. [15] It reduces the dependency on food crops as compared to production from edible oils. The non-edible oil is cheaper compared to edible oils [21]. The non-edible crops may be grown on any wastelands, no requirement of agricultural land, water sources, and fertilizers. It facilitates to solve the problem of treating, recycling and disposing of oil waste. The process also helps in preventing blockages in drainage systems and thus minimizes water pollution [15, 16].

The non-edible crops are not suited for human consumption because they may contain some toxic compounds [20]. If the free fatty acid is more than 2.5%, it may result in the formation of soap during the reaction. Thus the emulsion formed during the reaction will make the separation of glycerol and biodiesel difficult. Therefore the oil has to undergo pretreatment process before transesterification reaction [15]. The biodiesel produced is of lower quality compared to the fuel produced from edible oils. It is difficult to handle the fuel,- because it converts into solid at room temperature [20]. The commonly used non-edible oils are from sources such as Jatropha curcas, Pongamiapinnata, Moringaoleifera, Calophylluminophyllum, Castor oil, Neem, sea mango, Yellow oleander, Mahua and Rubber [21]. The final biodiesel produced is portable, easily available, having high heat content, containing lower sulfur and aromatic content and biodegradable. But at the same time, it has drawbacks that fuel has high viscosity and volatility and also high cost. The fuel produced meets the standard ASTM quality and prescribed emission characteristics [18].

The sources waste oily streams from the refineries, waste grease (yellow grease and brown grease) have free fatty acids higher than 4%. The fuel obtained from these low-cost sources are generally known as third generation biodiesel [15, 20]. It does not require any land or water usage and is an effective method for disposing of the oil waste. Since they have high fatty acid content, these wastes are subjected to purification, filtration, pre-esterification, transesterification [20], then and then the viscosity of the oil can be reduced considerably by mixing with diesel oil [17].

CATALYSTS USED FOR TRANSESTERIFICATION REACTION

The different types of a catalyst like alkaline and acid catalyst are used for carrying out transesterification reaction. Also homogenous and heterogeneous catalyst is also important in deciding the biodiesel conversion. The advantages and drawbacks of various catalyst, its features and its significant influence in the transesterification reaction are discussed below.

Alkali Catalyst

The process employing alkaline catalyst is considered as effective because there is no corrosion, the reaction occurs faster at a low temperature, the time needed for the reaction is less [22, 23]. They have reaction rates 4000 times faster when compared to the acid catalyst. It is generally suitable in the commercial applications [16].

It has the disadvantages such as because of the presence of free fatty acid and water in the feed, there may be a possibility of soap formation and thus it makes the separation process difficult. Due to this the catalyst activity decreases and the yield of biodiesel reduces [18, 19, 22, 23]. The washing process requires a lot of energy, recovering glycerol may be difficult [3, 23]. The alkali catalysts used are sodium hydroxide, sodium methoxide, and potassium methoxide.

Acid Catalyst

The acid based transesterification process was carried out using the mineral acids such as sulfuric acid, hydrochloric acid or phosphoric acid. The process has high yield, low reaction rate, causes corrosion, may damage the process equipment and raises environmental issues. The process is advisable if the oil mixture contains higher fatty acids and water content generally non-edible oils [3, 19, 23]. For a feed containing higher free fatty acids content, the process is generally used as the preliminary step for converting fatty acids to esters. By improving the operating conditions such as the ratio of alcohol to oil, temperature, reaction time, catalyst concentration the yield can be increased [22, 3, 18].

Since the process requires a large amount of alcohol, the size of the process column needed is large [22]. The

system requires high alcohol to triglyceride content in the feed mixture [16].

Homogeneous and Heterogeneous Catalyst

The catalyst is homogeneous in nature when the catalyst is present in the liquid phase and is same as that of reactants of the transesterification process. The catalyst is considered as heterogeneous if the catalyst appears in a solid, immiscible liquid or gaseous phase which is not similar to the feed mixture [19].

Homogeneous catalysts are very simple to use, needs lesser time for the process completion and can be operated in low severe operating conditions [18]. It has drawbacks such as reusing of the catalyst is not possible, the process consumes a lot of energy, washing, and separation of the two phases is costly and difficult, it produces a lower grade glycerol and the time required is more [3, 19, 24]. By using heterogeneous catalyst the process produces a large quantity of wastewater [18]. The homogeneous catalysts generally include sulfuric acid, hydrochloric acid, phosphoric acid, sodium hydroxide, potassium hydroxide and potassium methoxide.

Heterogeneous catalyst does not dissolve in the feed mixture and thus separation can be done easily and reused [3]. It has features that after the transesterification step the two phases can be easily separated, purification is easier, catalyst, can be reused, the process becomes cheaper, soap is not formed and environmentally friendly process. It also has the advantages that the process results in high yield of biodiesel, high purity glycerol, and cost of the catalyst decreases. The process can be carried out at high severe operating conditions [3, 19]. The catalyst can be used for a long time and can be disposed of easily [16]. By using these catalysts the reaction becomes slower and the three-phase mixture of oil–alcohol–catalyst is formed which has the poor mass transfer. Therefore another solvent has to be added to increase the mass transfer and diffusion in the reaction system [16, 22]. The activity of the catalyst depends on various operating conditions temperature, the quantity of the catalyst, reaction time, degree of mixing and feedstock [24]. Commonly used heterogeneous catalysts are metal oxides, zeolite, Al_2O_3, BaO, SrO, CaO, MgO [3].

THE INFLUENCE OF OPERATING CONDITIONS ON THE TRANSESTERIFICATION REACTION

The factors which influence the production and yield of biodiesel in the transesterification reaction are mainly the molar ratio of alcohol to feed oil, system temperature, catalyst concentration and reaction time.

The Effect of Alcohol to Oil Ratio on the Transesterification

The increase in the alcohol to oil ratio enhances the solubility of the catalyst, converts triglycerides to monoglycerides, the reaction progresses and the yield of biodiesel increases [25, 26]. It was reported that large quantity of alcohol is required for the reaction system having acid catalyst whereas a little amount of alcohol is sufficient for the system using alkaline catalyst [27]. When the alcohol to oil ratio increases generally over 15:1, one of the byproducts of the reaction glycerol dissolve in the excess alcohol and inhibits the transesterification reaction and thus reduces the yield [28, 29]. At alcohol to oil ratio of 1:3 which is lower than the stoichiometric ratio, the alcohol vaporizes continuously and the biodiesel conversion may be affected [4, 30].

The Influence of Temperature on Transesterification

It was studied that with the increase in temperature the reaction rate increases for an endothermic reaction and hence the higher biodiesel yield is obtained [25, 30]. This is due to the reason that by increasing temperature, the kinetic

energy of the reactants in the system increases and mass transfer among the reactants and the catalyst increases [31]. Also, the viscosity of the oil decreases and leads to proper mixing of oil and alcohol and promotes the reaction. (0879) At higher temperatures above 60^{o}C, methanol may be lost, catalytic activity decreases and solubility problems and results in the decrease in yield [30, 31].

The Effect of Catalyst Concentration and Time on the Process

The catalyst concentration plays a vital role in the transesterification process. By increasing the catalyst concentration from 1 to 3% in the feed mixture, the biodiesel yield increases [30]. The catalyst has active sites which are useful for the interaction of the reactants in the system and the biodiesel yield increases [31]. It was also reported that with the excess use of the catalyst, emulsion formation takes place and viscosity of the oil increases, therefore the yield of biodiesel decreases [7]. As the reaction time increases, there is an increase in the biodiesel yield. This is due to the fact that with the increase in reaction time, the sufficient energy is achieved in the system which will shift the reaction towards biodiesel production [32].

From the available literature, it was studied that different works are carried out for the production of biodiesel. The works describe the various feedstocks used for the biodiesel production. It explains the different catalysts used and the various operating conditions maintained for the production process. The summarization of all the parameters like feed - stocks used, catalysts used, type of esterification process, the operating conditions like the ratio of methanol to oil, the percentage of catalyst, operating temperature, reaction time and percentage yield are listed in Table1. The interesting findings from the recent literature such as the advantage of using heterogeneous catalyst, the excess ratio of methanol used in the feed mixture, the influence of excess of oil present in the feed, the other possible solvents that can be used and other issues of commercializing of the process and finding low cost feedstocks are discussed below.

It was reported by Kansedo et al. that biodiesel yield from sea mango oil by using homogeneous catalyst sodium hydroxide was only 8.3%. But using by using heterogeneous catalyst montmorilonite and sulfated zirconia alumina the yield was above 48.3 and 83.8% respectively. The authors have explained that excess free fatty acids present in the oil can react with homogeneous catalyst and leads to the formation of soap and reduce the yield of biodiesel. But the heterogeneous catalyst has more active sites which facilitate transesterification process and enhances the yield [33]. Turbonillastriatula shells waste was reused for the heterogeneous catalyst preparation. The waste contained a higher percentage of CaO which was beneficial for the transesterification process [34]. The feasibility and activity of the catalyst were studied by reusing the catalyst again and again in the transesterification reaction. The authors observed that the activity of the catalyst decreased and biodiesel yield decreased considerably after 12 reaction cycles. This was because of the reason that surface structure of the catalyst changes and the calcium oxide gets converted into calcium hydroxide because of the moisture content present in the reactants. It was also reported that the activity can be obtained back by subjecting to calcination in the presence of air at a higher temperature [35].

The paper by Suryaputra et al. reported that the heterogeneous catalyst has the benefits that it can be reused and it is stable in nature. This was tested by conducting three cycles of transesterification reaction [36]. Boro et al. explored from the reusability experiments that the decrease in activity of the barium doped CaO catalyst takes place. It was because of the reason that active sites are lost during the reaction and the product gets deposited on the surface of the catalyst [31]. The catalyst from eggshells was prepared by subjecting the waste shells to calcination, hydration and dehydration steps. It was found that the prepared catalyst had high activity because of the presence of calcium carbonate in the waste shells [37]. The

calcium oxide produced from different feedstocks as a catalyst has various applications in the transesterification process. The catalyst is less soluble in biodiesel and methanol, noncorrosive in nature, can be recycled and it is environmentally favorable. By employing this catalyst the generation of wastewater can be reduced and the process becomes cheaper [38]. Endut et al. reported that using heterogeneous catalyst wastewater produced can be minimized and separating the catalyst from the biodiesel are easier [39].

The heterogeneous catalyst from eggshell ash was reused more than ten times for transesterification reaction and it was proved that by reusing the catalyst the overall cost of the process can be brought down [40]. The potential of Pomacea sp. shell derived CaO as the heterogeneous catalyst was investigated by Margaretha et al. The catalyst has the properties that it is highly alkaline, cheaper compared to other catalysts, easy to handle, reusable and stable when used for the large scale production [2]. It was reported that mass transfer is limited in the systems having a heterogeneous catalyst, thus the large quantity of methanol is used for the transesterification reaction. The authors studied that using an excess of methanol results in difficulties in recovering of biodiesel and also the process increases [4].

A new catalyst namely chlorosulfonic acid was used for the biodiesel production. It has the advantage that both the esterification and transesterification reactions are catalyzed by chlorosulfonic acid. It also minimizes the inhibition in the esterification due to the water formed during the reaction and enhances the kinetics of the reaction [8].

Schinas et al. reported that the feedstock having higher oil content reduces the operational costs required for the biodiesel production. It was explained with the help of pumpkin seed which had a oil content of 42% to 45% results in lower operating costs compared to soybeans and cotton seeds, which had only in the range of 20% and 14%, respectively [41]. It was studied that the HodgsoniaMacrocarpa seed oil has a higher oil content of 71.65 wt% compared to other materials like cotton seed cake, Forsythia suspense, Xylocarpusmoluccensis, Calotropis gigantean and Jatropha curcas. From this, it can be proved that by having higher oil content, the material will have lower acid value. Thus the material having low acid value can be processed directly into alkaline transesterification process without any pretreatment process [42].

Venkanna and Reddy investigated on the treatment of biodiesel produced from Honne oil after the transesterification process. After the transesterification process, the lighter top layer which contains esters and some portion of unreacted feed oil was mixed with fresh methanol. The esters (biodiesel) mixes thoroughly with methanol. But the unreacted feed oil is formed as a separate layer which can be easily separated. Therefore they concluded that the product purity can be improved by this method [43]. The research done by Holilah et al. on the biodiesel production from Reutealistrisperma, it was reported that for a large ratio of methanol to oil in the transesterification reaction it will take longer time for the separation of the biodiesel from the methanol [25]. Methanol the primary solvent used for transesterification process is generally considered as non-renewable and is produced from fossil resources. Thus the production process can be made more effective by selecting alcohols obtained from bio sources. The authors have used alcohols like butanol, propanol, and pentanol for the biodiesel production. It was found that the yield obtained with these solvents was promising [44].

The authors in the work examined the feasibility of using different feed stocks such as waste frying oil, palm oil, and waste fish oil separately and together as a mixture of these feedstocks. It was observed that some of the properties of the biodiesel produced were better when the feedstocks were used independently. Also, the other properties were improved when the feedstocks were used in combination [45]. Rahman et al. explored the biodiesel production from the green source

such as Spirulina maxima algae and it was proved that the feed stock is biodegradable in nature, non-toxic and the biodiesel produced stands in par with the biodiesel produced from fossil sources in terms of properties [46].

The issue of commercializing biodiesel and the high cost involved in the process was addressed by Atapour and Kariminia. The authors have attempted to produce biodiesel from low-cost material like Iranian almond oil which will reduce the cost of the process [47]. Lai et al. used rice bran oil for the biodiesel production to solve the problem of using expensive feedstock for biodiesel. Thus it will minimize the cost of the transesterification process [48]. The feasibility of using non-edible oils over edible oils was described by Atabani et al. The edible oils contain free fatty acids in less percentage and therefore the biodiesel yield is higher. But by using the edible oils for biodiesel production leads to problems such as food security, deforestation and excessive use of agricultural land. Therefore the above issue was discussed by using Pangiumedule oil for biodiesel production [49].

Table 1: The Summarization of the Parameters Like the Feed Stock used, Type of Transesterification, the Catalyst used, the Operating Conditions used and the Percentage Yield

Sl. No	Feed Stock	Process Technique Employed	Catalyst	Operating conditions				% Yield	Ref.
				Ratio of Methanol to oil	Ratio of Catalyst to oil	Reaction Temperature	Reaction Time, min		
1	Pumpkin seed oil	Alkaline transesterification	NaOH	6:1	1 wt%	65°C	60	97.5	[41]
2	Dairy scum oil	Alkaline transesterification	Potassium hydroxide	4.5:1 to 9:1	0.8 to 1.2 wt%	48 to 62°C	45 to 75	93	[50]
3	Iranian almond oil	Alkaline transesterification	Sodium hydroxide	5.5:1 to 12.5:1	0.5 to 1.5wt%	35 to 65°C	60	96.27	[6]
4	Chinese tallow oil	Heterogeneous transesterification	Fresh water mussel shell	9:1 to 15:1	4 to 6 wt%	70°C	90	90	[35]
5	Acorn Kernel Oil	Two stage transesterification	Potassium hydroxide	3:1 to 15:1	0.5 to 2wt%	30 to 60°C	10 to 80	92	[51]
6	Sea mango oil	homogeneous transesterification	NaOH	6:1 mol/mol	0.1 wt%	64.7°C	60	8.3	
		Heterogeneous transesterification	Montmorillonite KSF	10:1	4 wt%	150°C	120	48.3	
			sulfated zirconia alumina	8:1	5 wt%	180°C	180	83.8	
	Palm oil	homogeneous transesterification	NaOH	6:1 mol/mol	0.1 wt%	64.7°C	60	78.1	
		Heterogeneous transesterification	Montmorillonite KSF	10:1	4 wt%	150°C	120	78.7	
			sulfated zirconia alumina	8:1	5 wt%	180°C	180	82.8	[33]
7	Zanthoxylumbungeanum seed oil	Acid catalyst transesterification	H_2SO_4	4:1 to 40:1	0.5 to 3.0 wt %	40 to 65°C	20–120		
		Alkaline catalyst transesterification	KOH	4:1 to 24:1	0.5 to 3.0 wt%	40 to 60°C	60-120	98	[52]
8	P. edule oil	Two stage transesterification	Potassium hydroxide	6:1	1 wt%	60°C	120		[49]
9	Calophyllum inophyllum linn oil	Three stage transesterification process	KOH	4:1, 6:1, 8:1 and 10:1	0.75–1.5wt% of oil	45, 55, 60 and 65°C	30 to 150	89	[43]
10	Palm olein	Heterogeneous catalyst	waste mud crab (Scylla serrata) shell as catalyst	0.25 and 0.75 g/g	1.6, 8.4 wt%	40, 90°C	150	98.8	[53]
11	mahua (Madhucaindica) oil	Two step transesterification process	KOH	0.15 to 0.40	0.7 wt%	60°C	30 to 120	98	[54]
12	mustard oil	Heterogeneous transesterification	Solid oxide from Turbonillastriatula shells	3:1 to 12:1	1 to 3 wt%	60 to 70°C	360	81	[34]

Table 1: Contd.,									
13	Sapindusm ukorossi oil	Two stage transesterification process	Sodium methoxide	4:1 to 12:1	0.5 to 1.5 wt%	65°C	120	92.5	[55]
14	M. zapota oil	Two step transesterification	Potasium methoxide	4:1 to 8:1	0.5 to 1.5 wt%	50 to 70°C	60 to 120	94.83	[56]
15	seashore mallow	Two stage transesterification process	Sodium methoxide	6:1	0.5 wt%	60°C	60	94	[57]
16	Refined palm oil	Heterogeneous transesterification	Waste capiz shell (Amusiumcristatum)	8:1	1 to 5wt%	60°C	240 to 360	93	[36]
17	soybean oil	Heterogeneous transesterification	Rice husk ash (Li-modified) as catalyst	3:1 to 24:1	1 to 5wt%	65°C	180	99.5	[58]
18	waste cooking oil	Heterogeneous transesterification	waste mollusk shells (Ba doped)	6:1 to 12:1	0.5 to 1.5wt%	55°C	60	98	[31]
19	Refined sunflower oil	Heterogeneous transesterification	Gold silver nanoparticle	5:1	5 wt%	65°C	120	86.9	[59]
20	Refined palm oil	Heterogeneous transesterification and sonication	Ostrich egg shell derived CaO catalyst	3:1 to 15:1	3 to 10wt%	60°C	60-180	92.7	[28]
21	waste frying oil	Heterogeneous transesterification	Egg shell derived CaO catalyst	12:1	5 wt%	65°C	60	90	[37]
22	Norouzak seeds oil	Alkaline transesterification (sonication)	Potassium hydroxide	5:1 to 7:1	1 wt%	45°C	9	97.60	[60]
23	Hodgsonia macrocarpa seed oil	Alkaline transesterification	Sodium hydroxide	4:1 to 12:1	1 wt%	50 to 80°C	120	95.46	[42]
24	waste fish oil	Two stage transesterification	Sodium hydroxide	9:1	0.5 wt%	60°C	60	85.00	
	palm oil	Two stage transesterification	Sodium hydroxide	9:1	0.5 wt%	60°C	60	87.1	
	waste frying oil	Two stage transesterification	Sodium hydroxide	9:1	0.5 wt%	60°C	60	87.6	[45]
25	shea butter oil	Two stage transesterification	Potassium hydroxide	3.5:8.5	0.6 to 1.6%	60 to 90°C	30 to 75	95.9	[61]
26	Waste fish oil	Two stage transesterification (sonication)	Potassium hydroxide	3:1 to 12:1	0.5 to 2wt%	40 to 60°C	30	79.86	[62]
27	rubber seed oil	Heterogeneous transesterification	SO_3H-MCM-41 catalyst	16:1	5 to 15wt%	100 to 140°C	720 to 2880	83.10	[63]
28	Soybean oil	Heterogeneous transesterification	Egg shell derived CaO as catalyst	6:1 to 12:1	3.5 to 14 wt%	25°C	540	96	[38]
29	Karanja oil	Two stage transesterification (alcohol 1-butanol)	Potassium hydroxide	6:1 to 15:1	0.5 to 2wt%	50 to 80°C	60 to 120	76.4	
	Karanja oil	Two stage transesterification (alcohol 1-pentanol)	Potassium hydroxide	6:1 to 15:1	0.5 to 2wt%	50 to 80°C	60 to 120	73.13	
	Karanja oil	Two stage transesterification (alcohol 2-propanol)	Potassium hydroxide	6:1 to 15:1	0.5 to 2wt%	50 to 80°C	60 to 120	56.86	[44]
30	hazelnut oil	Alkaline transesterification	Potassium hydroxide	6:1	0.7 wt%	60°C	120	97.5	
	sunflower oil	Alkaline transesterification	Potassium hydroxide	6:1	0.7 wt%	60°C	120	97.3	
	Mix. of hazelnut and sunflower (1:1 v/v)	Alkaline transesterification	Potassium hydroxide	6:1	0.7 wt%	60°C	120	97.9	[64]
31	Soybean oil	Heterogeneous transesterification	sodium zirconate	15:1 to 30:1	0.5 to 3 wt%	45°C	60 to 120	96	
	Soybean oil	Heterogeneous transesterification	Cesium modified sodium zirconate	15:1 to 30:1	1 wt%	45°C	15 to 30	98.8	

Table 1: Contd.,									
	Jatropha oil	Heterogeneous transesterification	sodium zirconate	15:1 to 30:1	1 to 3wt%	45°C	60 to 180	90.7	
	Jatropha oil	Heterogeneous transesterification	Cesium modified sodium zirconate	15:1	3wt%	45 to 85°C	30 to 120	90.8	[65]
32	Shea butter oil	Two stage transesterification	Potassium hydroxide	4:1 to 8:1	1 to 2wt%	40 to 60°C	120	92.16	[66]
33	Palm oil	Heterogeneous transesterification	Coconut shell derived catalyst	30:1	6 wt%	60°C	360	88.15	[39]
34	Waste vegetable	Heterogeneous transesterification	Egg shell ash derived catalyst	15:1 to 30:1	2 to 5wt%	60 to 70°C	330	74.02	[40]
35	Waste fish oil	Two stage transesterification	Potassium hydroxide	6:1 to 12:1	0.5 to 1.5wt%	60°C	60 to 120	99.1	[67]
36	Spirulina maxima algal oil	Two stage transesterification	Potassium hydroxide	6:1 to 12:1	0.5 to 1.5wt%	45 to 65°C	60	86.1	[46]
37	Neem oil	Heterogeneous transesterification	CaO from waste crab shells impregnated with Na-ZSM-5	12:1	15%	75°C	360	95	[68]
38	Palm oil	Heterogeneous transesterification	Pomacea sp. shell derived catalyst	5:1 to 11:1	1 to 5wt%	60°C	240	95.61	[2]
39	Neem oil	Two stage transesterification	Sodium hydroxide	1.5:1 to 7.5:1	0.45 to 1.45wt%	45 to 65°C	45 to 65	89.69	[69]
40	Oleander oil	Two stage transesterification (sonication)	Potassium hydroxide	4:1	0.75 wt%	50°C	15	97.1	[14]
41	Castor oil	Alkaline transesterification	Potassium hydroxide	4.5:1 to 10.5:1	0.5 to 1.5 wt%	35 to 65°C	40	92	[70]
42	Reutealistri sperma oil	Two stage transesterification	Sodium hydroxide	1:1 to 1:3	0.5 to 2wt%	30 to 70°C	60	95.15	[25]
43	Kesambi oil	Heterogeneous transesterfication	Alumina supported zinc oxide	6:1 to 18:1	1 to 6wt%	65°C	420	92.29	[4]
44	Jatrophacur cas oil	Acidic transesterification (sonication)	Chlorosulfonic acid	10:1 to 30:1	1 to 9wt%	30 to 60°C	240	93	[8]

CONCLUSIONS

The present study investigates the various feedstock materials used for biodiesel production. The edible oil, non-edible oil, and waste cooking oils can be used for the preparation of biodiesel by transesterification process. The biodiesel produced from edible oils have high yield compared to non-edible oils and waste cooking oils. But this may result in problems such as food security when depended more on the edible oils. The paper reviews the catalyst used such as alkaline, acidic and homogeneous, the heterogeneous catalyst used for the transesterification process. It also explores the different operating conditions such as molar ratio of alcohol to oil, the percentage of catalyst in the feed mixture, operating temperature and reaction time. Therefore it can be concluded that the biodiesel yield depends on the type of feedstock, its oil content, a composition of free fatty acids and the experimental operating conditions. It was also found that the selection of feed -stock is an important factor since the commercialization of biodiesel production plant depends on the type of feed -stock selected.

REFERENCES

1. *I. Shahzadi, S. Sadaf, J. Iqbal, I. Ullah, H. N. Bhatti, 'Evaluation of mustard oil for the synthesis of biodiesel: Pretreatment and optimization study', Environmental Progress & Sustainable Energy, (2017) 1-7.*
2. *Y.Y. Margaretha, H. S. Prastyo, A. Ayucitra, S. Ismadji, 'Calcium oxide from Pomacea sp. shell as a catalyst for biodiesel production', International Journal of Energy and Environmental Engineering, 3(1) (2012) 33.*

3. *E.M. Shahid, Y. Jamal, 'Production of biodiesel: a technical review', Renewable and Sustainable Energy Reviews, 15(9) (2011) 4732-4745.*
4. *N. P. Asri, S. Soe'eib, B. Poedjojono, 'Alumina supported zinc oxide catalyst for production of biodiesel from kesambi oil and optimization to achieve highest yields of biodiesel', Euro-Mediterranean Journal for Environmental Integration, 3(1) (2018) 3.*
5. *S.K. Karmee, 'Enzymatic biodiesel production from Manilkarazapota (L.) seed oil', Waste and Biomass Valorization, 3(3) (2017) 1-6.*
6. *M. Atapour, H. R. Kariminia, 'Optimization of biodiesel production from Iranian bitter almond oil using statistical approach', Waste and Biomass Valorization, 4(3) (2013) 467-474.*
7. *P. Verma, M. P. Sharma, 'Review of process parameters for biodiesel production from different feedstocks', Renewable and Sustainable Energy Reviews, 62 (2016) 1063-1071.*
8. *H. A. Choudhury, P. Srivastava, V.S. Moholkar, 'Single-step ultrasonic synthesis of biodiesel from crude Jatrophacurcas oil', AIChE Journal, 60(5) (2014) 1572-1581.*
9. *F. Halek, A. Delavari, A. Kavousi-rahim, 'Production of biodiesel as a renewable energy source from castor oil', Clean Technologies and Environmental Policy, 15(6) (2013) 1063-1068.*
10. *S.B. da Silva, V.A. dos Santos Garcia, P.A. Arroyo, C. da Silva, 'Ultrasound-assisted extraction of radish seed oil with methyl acetate for biodiesel production', The Canadian Journal of Chemical Engineering, 95(11) (2017) 2142-2147.*
11. *N.S. Caetano, V.F. Silva, A.C. Melo, A.A. Martins, T.M. Mata, 'Spent coffee grounds for biodiesel production and other applications', Clean Technologies and Environmental Policy, 16(7) (2014) 1423-1430.*
12. *K.A. Borges, A.C.F. Batista, H. de Souza Rodrigues, M.H. Terrones, A.T. Vieira, M.F. de Oliveira, 'Production of methyl and ethyl biodiesel fuel from pequi oil (CaryocarbrasiliensisCamb.)', Chemistry and Technology of Fuels and Oils, 48(2) (2012) 83-89.*
13. *P. Adewale, M.J. Dumont, M. Ngadi, 'Recent trends of biodiesel production from animal fat wastes and associated production techniques', Renewable and Sustainable Energy Reviews, 45 (2015) 574-588.*
14. *A.K. Yadav, M.E. Khan, A. Pal, 'Biodiesel production from oleander (ThevetiaPeruviana) oil and its performance testing on a diesel engine', Korean Journal of Chemical Engineering, 34(2) (2017) 340-345.*
15. *N.M. Daud, S.R.S. Abdullah, H.A. Hasan, S. Yaakob, 'Production of biodiesel and its wastewater treatment technologies: a review', Process Safety and Environmental Protection, 94 (2015) 487-508.*
16. *G. Baskar, R. Aiswarya, 'Trends in catalytic production of biodiesel from various feedstocks', Renewable and Sustainable Energy Reviews, 57 (2016) 496-504.*
17. *A. Demirbas, A. Bafail, W. Ahmad, M. Sheikh, 'Biodiesel production from non-edible plant oils', Energy Exploration & Exploitation, 34(2) (2016) 290-318.*
18. *H.H. Mardhiah, H.C. Ong, H.H. Masjuki, S. Lim, H.V. Lee, 'A review on latest developments and future prospects of heterogeneous catalyst in biodiesel production from non-edible oils', Renewable and sustainable energy reviews, 67 (2017) 1225-1236.*
19. *M. Meira, C.M. Quintella, E.M.O. Ribeiro, H.R.G. Silva, A.K. Guimarães, "Overview of the challenges in the production of biodiesel', Biomass Conversion and Biorefinery, 5(3) (2015) 321-329.*

20. *S.B. Živković, M.V. Veljković, I.B. Banković-Ilić, I.M. Krstić, S.S. Konstantinović, S.B. Ilić, J.M. Avramović, O.S. Stamenković, V.B. Veljković, 'Technological, technical, economic, environmental, social, human health risk, toxicological and policy considerations of biodiesel production and use', Renewable and Sustainable Energy Reviews, 79 (2017) 222-247.*

21. *A.E. Atabani, A. da Silva César, 'Calophylluminophyllum L.–A prospective non-edible biodiesel feedstock. Study of biodiesel production, properties, fatty acid composition, blending and engine performance', Renewable and Sustainable Energy Reviews, 37 (2014) 644-655.*

22. *A. Karmakar, S. Karmakar, S. Mukherjee, 'Properties of various plants and animals feedstocks for biodiesel production', Bioresource technology, 101(19) (2010) 7201-7210.*

23. *L.C. Meher, D.V. Sagar, S.N. Naik, 'Technical aspects of biodiesel production by transesterification—a review', Renewable and sustainable energy reviews, 10(3) (2006) 248-268.*

24. *A. Galadima, O. Muraza, 'Biodiesel production from algae by using heterogeneous catalysts: A critical review', Energy, 78 (2014) 72-83.*

25. *H. Holilah, D. Prasetyoko, T.P. Oetami, E.B. Santosa, Y.M. Zein, H. Bahruji, H. Fansuri, R. Ediati, J. Juwari, 'The potential of Reutealistrisperma seed as a new non-edible source for biodiesel production', Biomass Conversion and Biorefinery, 5(4) (2015) 347-353.*

26. *N. Mansir, S.H. Teo, U. Rashid, Y.H. Taufiq-Yap, 'Efficient waste Gallus domesticus shell derived calcium-based catalyst for biodiesel production', Fuel, 211 (2018) 67-75.*

27. *Y.B. Jo, S.H. Park, J.K. Jeon, C.H. Ko, C. Ryu, Y.K. Park, 'Biodiesel production via the transesterification of soybean oil using waste starfish (Asterinapectinifera)', Applied biochemistry and biotechnology, 170(6) (2013) 1426-1436.*

28. *G. Chen, R. Shan, J. Shi, B. Yan, 'Ultrasonic-assisted production of biodiesel from transesterification of palm oil over ostrich eggshell-derived CaO catalysts', Bioresource technology, 171 (2014) 428-432.*

29. *P. Karuppiah Subramanian, P. Muthiah, 'Development of functionalized heterogeneous catalyst from Ceibapentandra stalk for biodiesel production using Sterculiafoetida seed oil', Environmental Progress & Sustainable Energy, 35(1) (2016) 308-314.*

30. *J. Li, Y.J. Fu, X.J. Qu, W. Wang, M. Luo, C.J. Zhao, Y.G. Zu, 'Biodiesel production from yellow horn (Xanthocerassorbifolia Bunge.) seed oil using ion exchange resin as heterogeneous catalyst', Bioresource technology, 108 (2012) 112-118.*

31. *J. Boro, L.J. Konwar, A.J. Thakur, D. Deka, 'Ba doped CaO derived from waste shells of T striatula (TS-CaO) as heterogeneous catalyst for biodiesel production', Fuel, 129 (2014) 182-187.*

32. *J. Lie, M.B. Rizkiana, F.E. Soetaredjo, Y.H. Ju, S. Ismadji, 'Production of biodiesel from sea mango (Cerberaodollam) seed using in situ subcritical methanol–water under a non-catalytic process', International Journal of Industrial Chemistry, 9(1) (2018) 53-59.*

33. *J. Kansedo, K.T. Lee, S. Bhatia, 'Cerberaodollam (sea mango) oil as a promising non-edible feedstock for biodiesel production', Fuel, 88(6) (2009) 1148-1150.*

34. *J. Boro, A.J. Thakur, D. Deka, 'Solid oxide derived from waste shells of Turbonillastriatula as a renewable catalyst for biodiesel production', Fuel Processing Technology, 92(10) (2011) 2061-2067.*

35. *S. Hu, Y. Wang, H. Han, 'Utilization of waste freshwater mussel shell as an economic catalyst for biodiesel production', Biomass and Bioenergy, 35(8) (2011) 3627-3635.*

36. *W. Suryaputra, I. Winata, N. Indraswati, S. Ismadji, 'Waste capiz (Amusiumcristatum) shell as a new heterogeneous catalyst for biodiesel production', Renewable Energy, 50 (2013) 795-799.*

37. *S. Niju, K.M. Meera S. Begum, N. Anantharaman, 'Modification of egg shell and its application in biodiesel production', Journal of Saudi Chemical Society, 18(5) (2014) 702-706.*

38. *A. Piker, B. Tabah, N. Perkas, A. Gedanken, 'A green and low-cost room temperature biodiesel production method from waste oil using egg shells as catalyst', Fuel, 182 (2016) 34-41.*

39. *A. Endut, S.H.Y.S. Abdullah, N.H.M. Hanapi, S.H.A. Hamid, F. Lananan, M.K.A. Kamarudin, R. Umar, H. Juahir, H. Khatoon, 'Optimization of biodiesel production by solid acid catalyst derived from coconut shell via response surface methodology', International Biodeterioration& Biodegradation, 124 (2017) 250-257.*

40. *N. Tshizanga, E.F. Aransiola, O. Oyekola, 'Optimisation of biodiesel production from waste vegetable oil and eggshell ash', South african journal of chemical engineering, 23 (2017) 145-156.*

41. *P. Schinas, G. Karavalakis, C. Davaris, G. Anastopoulos, D. Karonis, F. Zannikos, S. Stournas, E. Lois, 'Pumpkin (Cucurbitapepo L.) seed oil as an alternative feedstock for the production of biodiesel in Greece', Biomass and bioenergy, 33(1) (2009) 44-49.*

42. *L. Cao, S. Zhang, 'Production and characterization of biodiesel derived from Hodgsoniamacrocarpa seed oil', Applied Energy, 146 (2015) 135-140.*

43. *B.K. Venkanna, C.V. Reddy, 'Biodiesel production and optimization from Calophylluminophyllumlinn oil (honne oil)–A three stage method', Bioresource Technology, 100(21) (2009) 5122-5125.*

44. *P. Verma, M.P. Sharma, G. Dwivedi, 'Prospects of bio-based alcohols for Karanja biodiesel production: An optimisation study by Response Surface Methodology', Fuel, 183 (2016) 185-194.*

45. *V. F. de Almeida, P.J. García-Moreno, A. Guadix, E.M. Guadix, 'Biodiesel production from mixtures of waste fish oil, palm oil and waste frying oil: Optimization of fuel properties', Fuel Processing Technology, 133 (2015) 152-160.*

46. *M.A. Rahman, M.A. Aziz, R.A. Al-khulaidi, N. Sakib, M. Islam, 'Biodiesel production from microalgae Spirulina maxima by two step process: Optimization of process variable', Journal of Radiation Research and Applied Sciences, 10(2) (2017) 140-147.*

47. *M. Atapour, H.R. Kariminia, 'Optimization of biodiesel production from Iranian bitter almond oil using statistical approach', Waste and Biomass Valorization, 4(3) (2013) 467-474.*

48. *C.C. Lai, S. Zullaikah, S.R. Vali, Y.H. Ju, 'Lipase-catalyzed production of biodiesel from rice bran oil', Journal of Chemical Technology and Biotechnology, 80(3) (2005) 331-337.*

49. *A.E. Atabani, I.A. Badruddin, H.H. Masjuki, W.T. Chong, K.T. Lee, 'PangiumeduleReinw: a promising non-edible oil feedstock for biodiesel production', Arabian Journal for Science and Engineering, 40(2) (2015) 583-594.*

50. *K.V. Yatish, H.S. Lalithamba, R. Suresh, S.B. Arun, P.V. Kumar, 'Optimization of scum oil biodiesel production by using response surface methodology', Process Safety and Environmental Protection, 102 (2016) 667-672.*

51. *H. Karabas, 'The optimum production parameters of methyl ester from acorn kernel oil', Environmental Progress & Sustainable Energy, 33(2) (2014) 625-628.*

52. *J. Zhang, L. Jiang, 'Acid-catalyzed esterification of Zanthoxylumbungeanum seed oil with high free fatty acids for biodiesel production', Bioresource technology, 99(18) (2008) 8995-8998.*

53. *P.L. Boey, G.P. Maniam, S.A. Hamid, 'Biodiesel production via transesterification of palm olein using waste mud crab (Scylla serrata) shell as a heterogeneous catalyst', Bioresource Technology, 100(24) (2009) 6362-6368.*
54. *S.V. Ghadge, H. Raheman, 'Biodiesel production from mahua (Madhucaindica) oil having high free fatty acids', Biomass and Bioenergy, 28(6) (2005) 601-605.*
55. *M. Chakraborty, D.C. Baruah, 'Production and characterization of biodiesel obtained from Sapindusmukorossi kernel oil', Energy, 60 (2013) 159-167.*
56. *R.S. Kumar, K. Sureshkumar, R. Velraj, 'Optimization of biodiesel production from Manilkarazapota (L.) seed oil using Taguchi method', Fuel, 140 (2015) 90-96.*
57. *B.R. Moser, B.S. Dien, D.M. Seliskar, J.L. Gallagher, 'Seashore mallow (Kosteletzkyapentacarpos) as a salt-tolerant feedstock for production of biodiesel and ethanol', Renewable Energy, 50 (2013) 833-839.*
58. *K.T. Chen, J.X. Wang, Y.M. Dai, P.H. Wang, C.Y. Liou, C.W. Nien, J.S. Wu, C.C. Chen, 'Rice husk ash as a catalyst precursor for biodiesel production', Journal of the Taiwan Institute of Chemical Engineers, 44(4) (2013) 622-629.*
59. *M. Banerjee, B. Dey, J. Talukdar, M.C. Kalita, 'Production of biodiesel from sunflower oil using highly catalytic bimetallic gold–silver core–shell nanoparticle', Energy, 69 (2014) 695-699.*
60. *A. Hajinezhad, S. Abedi, B. Ghobadian, Y. Noorollahi, 'Biodiesel production from Norouzak (Salvia lerifolia) seeds as an indigenous source of bio fuel in Iran using ultrasound', Energy Conversion and Management, 99 (2015) 132-140.*
61. *E. Betiku, S.S. Okunsolawo, S.O. Ajala, O.S. Odedele, 'Performance evaluation of artificial neural network coupled with generic algorithm and response surface methodology in modeling and optimization of biodiesel production process parameters from shea tree (Vitellariaparadoxa) nut butter', Renewable Energy, 76 (2015) 408-417.*
62. *M. Maghami, S.M. Sadrameli, B. Ghobadian, 'Production of biodiesel from fishmeal plant waste oil using ultrasonic and conventional methods', Applied Thermal Engineering, 75 (2015) 575-579.*
63. *C. Samart, S. Karnjanakom, C. Chaiya, P. Reubroycharoen, R. Sawangkeaw, M. Charoenpanich, 'Statistical optimization of biodiesel production from para rubber seed oil by SO_3H-MCM-41 catalyst', Arabian Journal of Chemistry (2015)*
64. *A. Saydut, S. Erdogan, A.B. Kafadar, C. Kaya, F. Aydin, C. Hamamci, 'Process optimization for production of biodiesel from hazelnut oil, sunflower oil and their hybrid feedstock', Fuel, 183 (2016) 512-517.*
65. *D.A. Torres-Rodríguez, I.C. Romero-Ibarra, I.A. Ibarra, H. Pfeiffer, 'Biodiesel production from soybean and Jatropha oils using cesium impregnated sodium zirconate as a heterogeneous base catalyst', Renewable Energy, 93 (2016) 323-331.*
66. *E.O. Ajala, F. Aberuagba, A.M. Olaniyan, M.A. Ajala, M.O. Sunmonu, 'Optimization of a two stage process for biodiesel production from shea butter using response surface methodology', Egyptian Journal of Petroleum, 26(4) (2017) 943-955.*
67. *K. Kara, F. Ouanji, E.M. Lotfi, M. El Mahi, M. Kacimi, M. Ziyad, 'Biodiesel production from waste fish oil with high free fatty acid content from Moroccan fish-processing industries', Egyptian Journal of Petroleum (2017).*
68. *V. Shankar, R. Jambulingam, R., 'Waste crab shell derived CaO impregnated Na-ZSM-5 as a solid base catalyst for the transesterification of neem oil into biodiesel', Sustainable Environment Research, 27(6) (2017) 273-278.*
69. *O.O. Awolu, S.K. Layokun, 'Optimization of two-step transesterification production of biodiesel from neem (Azadirachtaindica) oil', International Journal of Energy and Environmental Engineering, 4(1) (2013) 39.*
70. *G.T. Jeong, D.H. Park, 'Optimization of biodiesel production from castor oil using response surface methodology', Applied biochemistry and biotechnology, 156(1-3) (2009) 1-11.*

71. *Krishna, MVS Murali, and K. Vamsi Krishna. "Studies on Exhaust Emissions of DI Diesel Engine with Low Grade LHR Combustion Chamber Fuelled with Linseed Biodiesel."*

72. *Ayoola, A. A., et al. "Comparison of the Properties of Palm Oil and Palm Kerneloil Biodiesel in Relation to the Degree of Unsaturation of their Oil Feedstocks." International Journal of Applied And Natural Sciences 5.3 (2016): 1-8.*